BELLCOMM, INC.
955 L'ENFANT PLAZA NORTH, S.W. WASHINGTON, D. C. 20024

B69 09029

SUBJECT: Evaluation of Computer Configurations for a Space Station - Case 730

DATE: September 15, 1969

FROM: B. W. Kim

ABSTRACT

Four computer configurations for a space station are compared for computation capability, lead time, risk, program manageability, programmability, adaptability, expandability, reliability, maintainability, and cost in weight, volume and power. The four configurations are the uniprocessor, the multiprocessor, the twin uniprocessor, and the dedicated uniprocessor systems.

Each configuration has some characteristic that makes it outstanding with respect to a particular criterion. The multiprocessor system has more of such characteristics than the other configurations, and hence it appears to be the most desirable.

N79-73145

(NASA-CR-109060) EVALUATION OF COMPUTER CONFIGURATIONS FOR A SPACE STATION (Bellcomm, Inc.) 11 p

Unclas
00/60 11719

FF No. 602(A)

11
(PAGES)

CR-109060
(NASA CR OR TMX OR AD NUMBER)

[redacted]

(CODE)

(CATEGORY)

BELLCOMM, INC.
955 L'ENFANT PLAZA NORTH, S.W. WASHINGTON, D.C. 20024

B69 09029

SUBJECT: Evaluation of Computer Configurations for a Space Station - Case 730

DATE: September 15, 1969

FROM: B. W. Kim

MEMORANDUM FOR FILE

I. INTRODUCTION

The computational capability needed to perform functions on board a space station can be provided by a variety of computer configurations. Four of these are described briefly and their characteristics are evaluated. The Mission Operation Module (MOM) concept of the space station, proposed by NASA/MSC, is assumed for this study. It has a basic subsystem module (BSM), a crew quarters module, an experiment module and a number of logistics/experiment modules.

The third computer generation is already in its maturity, and the fourth generation is expected to be introduced in the early 1970's. Since the space station is planned for the mid-1970's, fourth generation computer organizations such as array and associative processors could have been considered for it, but they were not because their lead time seems to be difficult to determine and their risk is therefore quite high. However, the circuitry to be used in any organization will most likely be that of the forthcoming technology, that is, large scale integration (LSI).

Since the evaluation is attempted only with the computer models at the black box level, the results are mostly qualitative. Quantitative results are provided wherever possible.

To evaluate a configuration, it is necessary in some cases to know what functions are performed and the computational capability necessary to perform them. It is assumed that the onboard functions will be guidance and navigation, attitude control, checkout, experiment handling and crew training. The requirement to handle these functions has been estimated from 100,000 operations/second and 30,000 memory words to 800,000 operations/second and 400,000 memory words if a great deal of experiment processing is done.*

II. COMPUTER CONFIGURATIONS

The four computer configurations evaluated are the uniprocessor, the multiprocessor, the twin uniprocessors and

*"Functional Requirements for the Spaceborne Computer System of a Mid-70's Space Station," D. O. Baechler, P. S. Schaenman (To be published).

the dedicated uniprocessors. They are selected primarily because of low risk involved, and reasonable and predictable lead times. Each of the systems will interface through their I/O units with a mass memory for programs and data, a number of multiplexors for communicating with sensors, and the telemetry system.

1. The Uniprocessor System

The uniprocessor system has a number of memory modules, a single processor and a single I/O unit (Figure 1). It is the most well established of the systems. It would be placed in the basic subsystem module of the space station and is by its nature a centralized system.

2. The Multiprocessor System

The multiprocessor can have a number of memory modules, a number of I/O units, a number of processor units, and an availability control unit (ACU) (Figure 2). The exact number of each unit will depend on the total functional requirements, the reliability and the expandability that is required. All of the units will be placed in the BSM and therefore it is a centralized system.

3. The Twin Uniprocessor System

Two independent uniprocessor systems comprise this system, (Figure 3). One will be placed in the BSM to handle the requirements of the guidance and navigation (G&N), pointing control and checkout. The other will be in the experiment module for the experiments and the training. Both will share the telemetry system in the BSM. The uniprocessor system in the experiment module may or may not have a mass memory depending on the scope of the experiment. This is a decentralized system.

4. The Dedicated Uniprocessor System

This system consists of five independent uniprocessors, each dedicated to one of the five functions, namely G&N and autopilot, pointing control, training, experiments and checkout (Figure 4). Placement of the systems can be very flexible. Each computer can be placed in a position closest to where the function is performed, and therefore this system is decentralized.

Improved reliability and maintainability may result by connecting all uniprocessor systems through I/O channels to form a configuration called a multicomputer system. All would then share the mass memory and the telemetry system and it would be possible, for instance, to substitute the training computer for the G&N computer. This configuration is not considered in this memorandum.

III. EVALUATION OF THE COMPUTER CONFIGURATION

The evaluation criteria are defined as follows:

Computation Capability is a measure of computation speed and effectiveness, and memory capacity.

Lead Time is the time from the date of order to the date of delivery.

Risk is the probability of engineering misconception, or prolonged lead time due to unexpected development difficulties.

Program Manageability is a measure of the ease with which software program additions and changes can be made.

Programmability is a measure of software programming ease.

Adaptability is a measure of the ease of meeting more than one set of requirements without hardware change.

Expandability is a measure of the ease of meeting more than one set of requirements with hardware change (such as modular increments).

Reliability is the probability that the system will perform satisfactorily during the mission.

Maintainability is the probability that the system or a subsystem which has failed is restored to operable condition in a specified down-time.

Cost is measured in weight (lbs.), power (watts) and volume ($ft.^3$).

Computation Capability

This criterion is relatively noncritical in the evaluation. Even a current uniprocessor system, the Litton L-3050, with 300,000 ops/sec. and 131,000 words can handle the lower estimates of the computer requirements of the space station, which are 100,000 ops/sec. and 30,000 memory words. The capability of the early 1970's uniprocessor systems is expected to be nearly 2,000,000 ops/sec. and 3,000,000 words.* This will be more than enough to meet even the highest estimates of requirements, which are 800,000 ops/sec. and 400,000 memory words.

*"Future Spaceborne Mass Memories," B. W. Kim, Bellcomm, Inc., Memorandum for File, October 23, 1968.

A multiprocessor system is even faster. Parallel operations among many CPU's and I/O's permit simultaneous manipulations of instructions and data. However, the throughput of a multiprocessor system is somewhat less than the product of the number of processors and the throughput of each because of the software overhead and the conflicts among the central processing units (CPU's) and I/O channels for the memory accesses.

The total throughput of the twin processor system is the sum of the throughputs of each processor since they are independent.

Likewise, the total throughput of the dedicated uniprocessor system is the sum of the throughputs of each dedicated uniprocessor. Hence, the speed of this system would be fastest. Also, the computation effectiveness would be the best because each processor subsystem will be designed or selected to handle each functional requirement in the most effective way. Even if a multicomputer configuration is desired by connecting each computer through the I/O units, the total throughput would be only slightly degraded, and the computation capability would still be greater than the other configurations.

Lead Time

The lead time is primarily a function of man-hour availability and soundness of software and hardware specifications. If specification changes and additions are so much as to affect the gross architectural level, the lead time may vary more than expected.

For all three uniprocessor cases, off-the-shelf computers with existing software may have a lead time of less than one year. Specially designed innovative systems may take four years.

Because of the complexity in hardware and software, the multiprocessor lead time may be longer than for other configurations.

Risk

No undue engineering and development risks are expected in any of the four configurations. More advanced computer configurations such as associative processors and processor arrays are purposely omitted here mainly because of the high risk and long lead time.

Program Manageability

Program manageability depends on complexity of the executive, memory capacity, instruction repertoire, library routines and degree of parallelism.

The centralized uniprocessor system and the multiprocessor system both have large memory capacities in a single unit rather than having the capacity divided among several units as in the decentralized systems. Therefore, their spare memory is all in one place and can be used in an increment that may be larger than any individual block of spare memory in a decentralized system. In addition, many library routines easily accessible in the centralized systems would tend to make program changes easier. Software for the uniprocessor system is somewhat easier to manage than for the multiprocessor system because the uniprocessor does not have the additional executive overhead that the multiprocessor system has.

On the other hand, each of the decentralized systems--the twin uniprocessor and the dedicated uniprocessor--would have simpler executives and less parallelism in operation than the centralized systems. The independence among programs would make it easier to add or change programs as long as there is sufficient memory to accommodate them.

Programmability

Programmability depends on availability of programming aids such as special routines, diagnostics, level of programming languages, assemblers, compilers and simulators. Since it would be more difficult to provide each of the dedicated computers with as many programming aids as the centralized computers would have, the centralized systems would have better programmability than the decentralized systems.

The difference between the uniprocessor and the multiprocessor systems would be slight, since the application programmer would scarcely be aware whether he is using a multiprocessor or a uniprocessor system.

Adaptability

Adaptability depends on the computer's ability to interface with a wide variety of spacecraft subsystems. This ability, in turn, depends on memory capacity, word length, number of interrupts and number and rate of each type of I/O channel. The centralized systems are more general purpose and therefore more adaptable at the cost of possibly lower efficiency in some applications.

On the other hand, the decentralized systems may have better adaptability when logistics make it more desirable for the computers to be located in different places to be close to the spacecraft subsystems with which they interface. The centralized systems would have to interface with spacecraft subsystems through I/O channels or multiplexor cables because the CPU's can not be separated.

Expandability

Expandability depends on modularity of memory, CPU and I/O modules. This modularity and the scope of expansion are predetermined by the system architecture. Expandability is provided at the cost of more hardware. Hence, it should be evaluated with this cost in mind.

Uniprocessor systems can usually have modular growth in memory. Expandability of the dedicated systems could probably be accomplished in smaller steps than the centralized system.

The multiprocessor system has the best expandability because it has the capability of modular growth in the CPU's as well as memory and I/O units. However, the computation capability of the multiprocessor system does not necessarily increase with the addition of a CPU since a proper balance of signal flow among memory, CPU and I/O units is required for the optimum computation capability.

Reliability

Reliability is related to the number and the type of each component and each electrical connection, and the environmental and application stresses. We assume that for all configurations, the most reliable design has been followed, and that further reliability increases can be obtained through the use of redundancy in the form of multicomputers, multiprocessors, distributed processors, component and circuit redundancies, and better maintainability.

Any single critical component or circuit failure in a non-redundant uniprocessor system would result in total system breakdown. In the dedicated uniprocessor and the twin uniprocessor systems, the situation would be the same in each computer, but any one computer failure would not result in total system breakdown. To improve the reliability in these uniprocessor systems, redundancy may be provided at the component or circuit level. The LSI technology makes this type of redundancy more feasible than it has been in the past. Also, redundancy at the replicated computer level is possible, particularly in some critical dedicated computers like the guidance and navigation computer.

The reliability of the multiprocessor system appears to be the best since the modular redundancy in the CPU's as well as I/O and memory units permits graceful degradation. Hence, it is least likely to have total breakdown. It is this feature of the multiprocessor system rather than the improved throughput that makes it most attractive for the space station. One study* reports that the redundant hardware of the multiprocessor system amounts to about half that required for operation at maximum allowable degradation, compared with redundancy ratios of one or two for replicated monolithic systems. Furthermore, the redundant hardware can be used more easily by a modular system than by a replicated central system.

Maintainability

Maintainability depends on the design repair level (circuit board, stack or module), hardware test (parity check, cycle time), software test (self test routines), system reconfiguration capability, spare parts etc.

Maintainability of a large uniprocessor system is limited because of the difficulty in fault isolation, spare replacement or reconfiguration during operation. Any critical failure may cause intolerable downtime.

Maintainability of the decentralized systems will in general be better. One of the reasons is that partial fault isolation is already provided by separation of the computers. Furthermore, from the maintainability standpoint, it appears advantageous to have identical computers since it would result in a smaller number of spares and simplified test procedures.

Maintainability of the multiprocessor system seems to be best, since a failed module can be isolated through automatic system reconfiguration, and repaired or replaced while the system is operating in a degraded mode.

Cost

Weight, power and volume of the four computer systems for the space station are estimated below. These estimates

---

*"Utilization of a Multiprocessor in Command and Control," B. Wald, Proceedings of the IEEE, December 1966.

do not include redundancy and cables, and are based on present day integrated circuits hardware.

The estimates for the multiprocessor system with one processor should be higher than those for the uniprocessor system because extra hardware is needed for the multiprocessor system to have the potential of modular growth. The amount of this extra hardware depends on the scope of modular growth, but would be little compared with the total system hardware.

	Weight (lbs.)	Volume (ft.^{3})	Power (watts)
Uniprocessor	230	3	600
Multiprocessor, 1 CPU.	>230	>3	>600
Twin Uniprocessor	350	5	800
Dedicated Uniprocessor	430	7	1300

The multiplexors to interface between the computers and the spacecraft subsystems are estimated to add about 70 lbs., 70 watts and 1.5 ft.^{3} in all cases.

Future LSI technology and better packaging methods will result in less weight and volume. However, increased hardware resulting from special features such as redundancy may reduce these advantages and may even increase the power consumption.

IV. CONCLUSION

There is no best computer configuration regarding all the evaluation criteria, but the multiprocessor configuration seems to best meet the collective criteria. The relative importance of each criterion should be considered in the final selection of the best configuration. Also, mission constraints may affect the selection. For instance, if the Experiment Module of the space station must have its own computer, the twin uniprocessor system may be considered a good answer.

Finally, there are other configurations that might be candidates for use on the space station. These include multicomputer systems, twin multiprocessors, dedicated multiprocessors, and hybrid systems such as dedicated uniprocessors and multiprocessors.

Bo W. Kim

1031-BWK-fcm B. W. Kim

Attachments

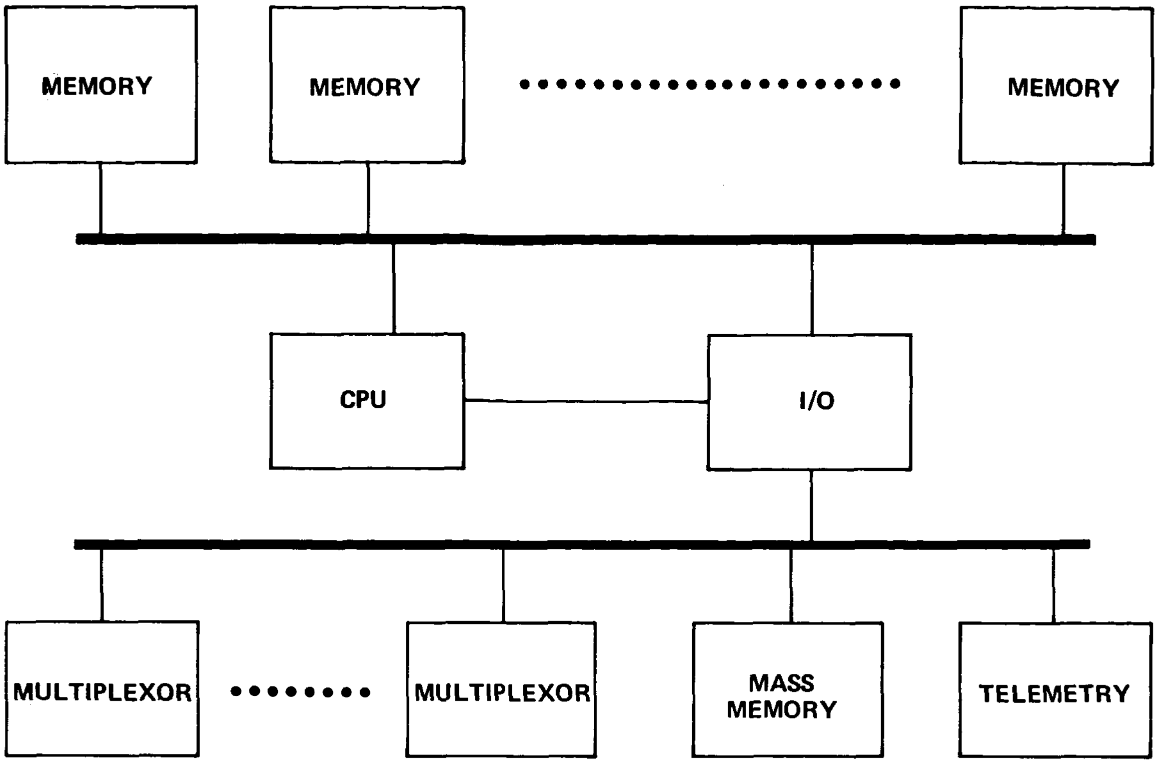

FIGURE 1 - UNIPROCESSOR SYSTEM

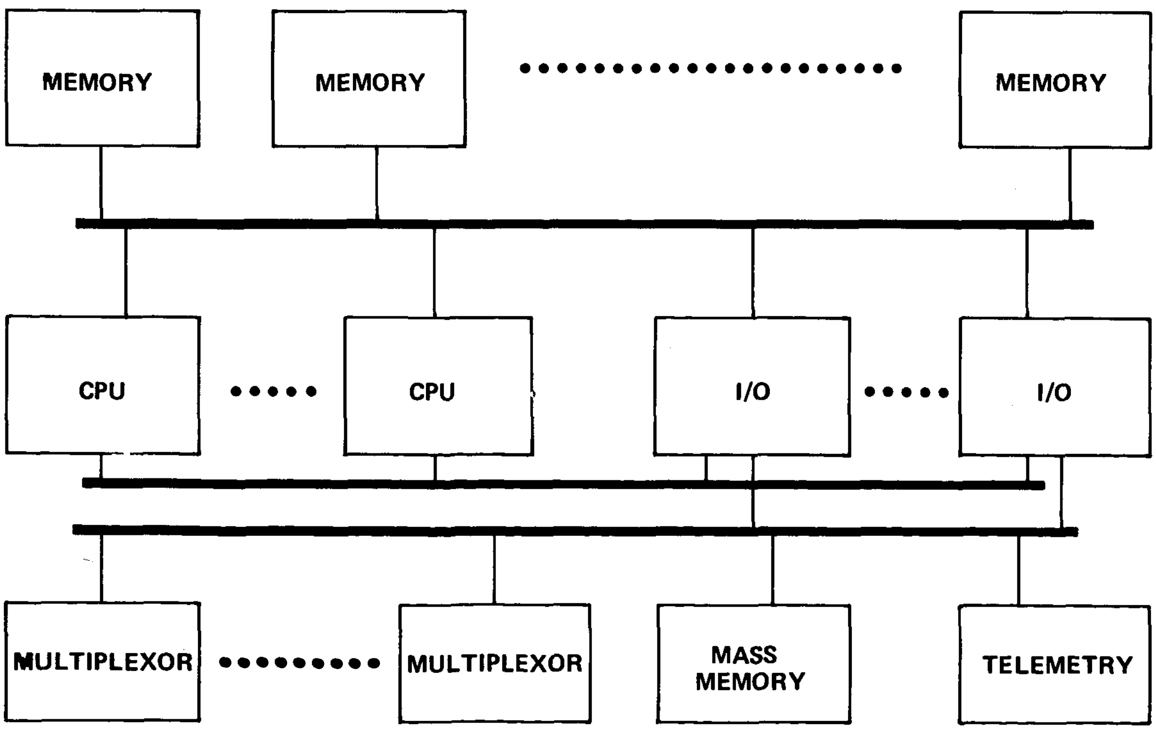

FIGURE 2 - MULTIPROCESSOR SYSTEM

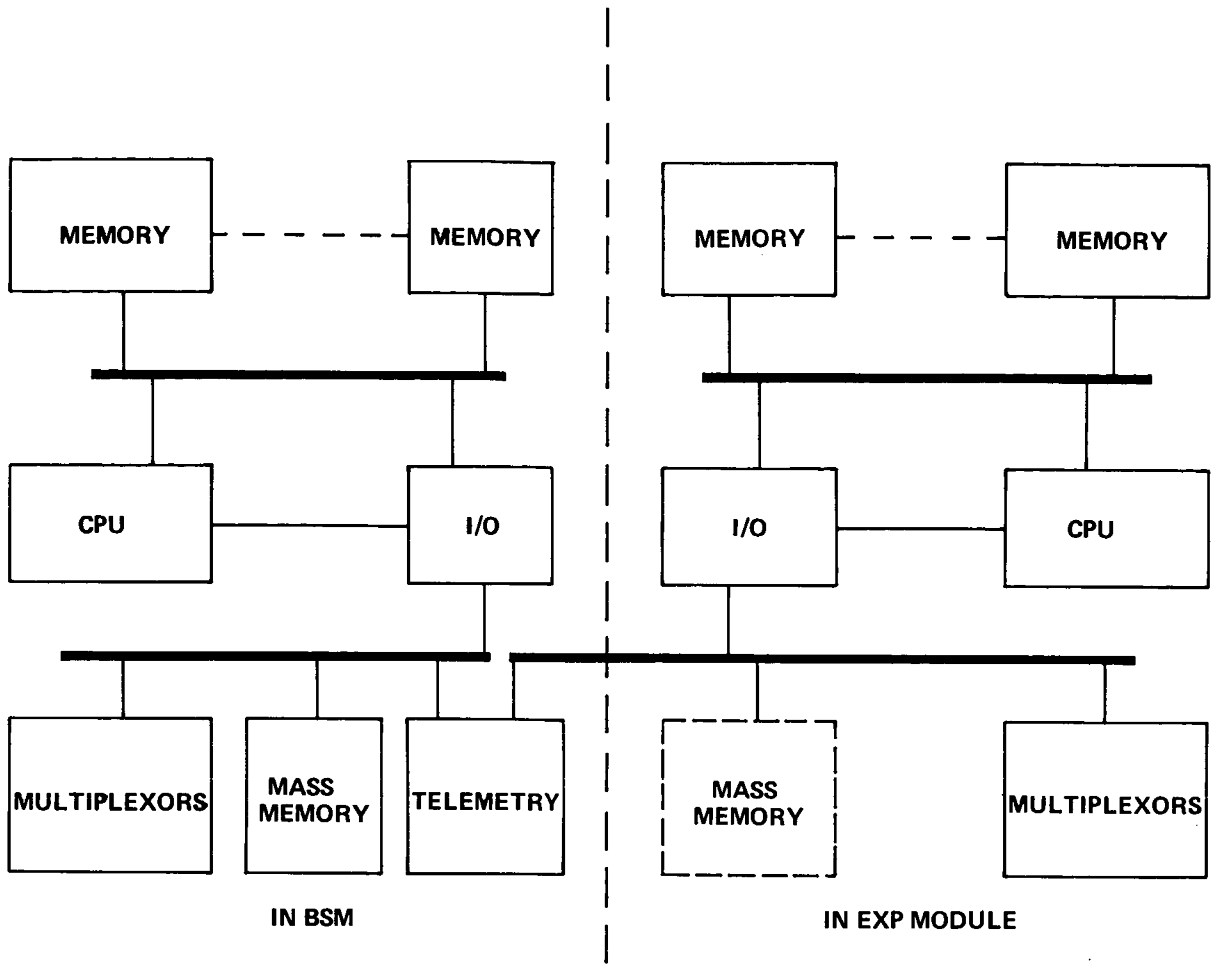

FIGURE 3 - TWIN UNIPROCESSOR SYSTEM

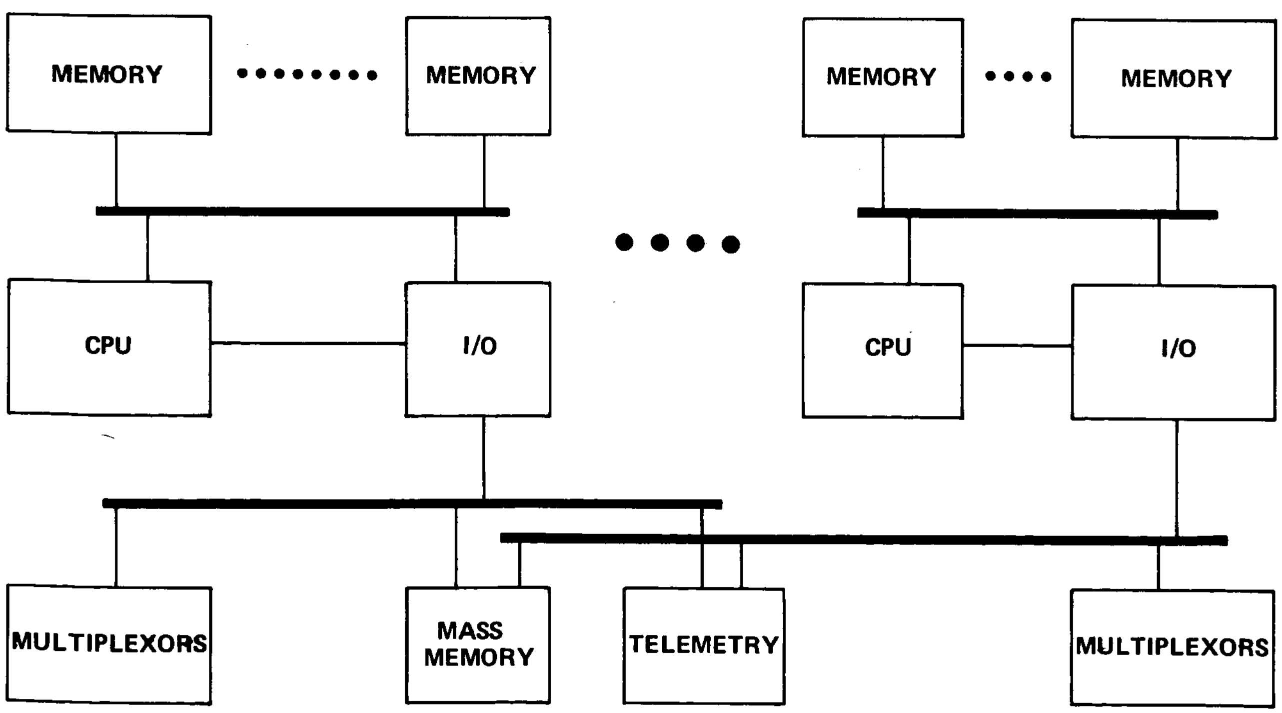

FIGURE 4 - DEDICATED UNIPROCESSOR SYSTEM